Generation Expansion Economic Evaluation

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I. Executive Summary

Additional power generation capacity is required in order to meet growth in US electricity demand coupled with the retirement of aging coal fired and nuclear plants. The traditional approach to new capacity requirements is the construction of new power generating plants. This requires a substantial investment in land, natural gas line and transmission system interconnections and upgrades, substation interconnection, new plant construction, additional plant staff and general plant annual O&M expenses including gas turbine major maintenance. An alternative to new plant construction is the harvesting of latent capacity from existing power plants at costs substantially less than new construction while leveraging sunk cost investments in existing facilities and plant staff. This analysis compares the capital cost, annual Operations and Maintenance ("O&M") costs and annual fuel costs of new generating plants with upgrading the capacity of existing generation facilities.

PowerPhase LLC ("PPL") provides a product that, when installed on an existing Combined Cycle Gas Turbine ("CCGT") unit, provides increased output at the host CCGT heat rate. The TurboPHASE Module ("TPM") compresses ambient air through a multi-staged, inter-cooled compressor driven by a turbocharged reciprocating engine. Each module is designed to deliver air at the gas turbine compressor discharge pressure and temperature. The TPM dry air injection system provides the missing compressor discharge air the gas turbine is lacking due to environmental or operational conditions. This process provides fast start and fast-ramp incremental power delivered across all ambient conditions, up to the mechanical or electrical limits of the plant. TPM utilizes existing plant and transmission system infrastructure to generate and deliver incremental capacity and energy.

The purpose of this study is to analyze and compare the capital costs, operating costs and fuel costs for (1) a new 1x1 7FA.05 CCGT plant, (2) a new 7FA.05 Simple Cycle Gas Turbine ("SCGT") plant, (3) an new LM 6000 PH Sprint SCGT plant and (4) TPM installed on a host 7FA.03 CCGT plant. All technologies are fueled by natural gas. While the absolute values of performance and cost may vary based on assumptions regarding performance degradation and actual dispatch profiles, this analysis provides a <u>relative</u> comparison through the consistent application of assumptions to each technology.

The CCGT case applies to a regulated utility or wholesale generator that needs additional intermediate to base load generating capacity throughout the year.

The SCGT case applies to a utility that requires additional summer seasonal peaking capacity to meet peak load demand. The 7FA.05 SCGT was selected since many utilities require peaking capacity in the near term while retaining the option to build out the SCGT to a CCGT in the long term. The LM 6000 was selected to represent the case in which the utility requires fast start with long term peaking and load following capability. When TPM is installed on a host CCGT to serve summer seasonal peaking requirements, additional CCGT energy and capacity become available throughout the year for additional sales or to economically displace coal generation.

Assumptions for the analysis were based on Energy Information Administration data, Gas Turbine World performance data, public sources as well as general power plant experience. Recognizing that each power plant will have its own specific costs and performance data, the objective of this analysis is to provide an indicative or "order of magnitude" cost comparison between technologies. The final technology selected would be subject to more thorough and project specific financial analysis.

The study results show that TPM provided the most economical incremental capacity among the technologies considered. When compared to a new 7FA.05 1x1 CCGT, TPM provided project capital cost savings of over $242 million and annual O&M savings of $9 million offset by an increase in annual fuel cost of $1.5 million. When compared to new SCGT plants, TPM provided capital cost savings ranging from $106 to $127 million, annual fuel savings of $2.5 to $3.2 million and annual O&M savings of $0 to $2 million. When capacity and energy are not required for peaking service, TPM energy used to displace existing legacy coal plant energy generates annual fuel cost savings of $4 million and annual O&M savings of $2 million.

II. Analysis Methodology

The analysis considered the following two cases: (1) an existing 2x1 7FA.03 CCGT unit with TPM compared to a new 1x1 7FA.05 CCGT plant, and (2) an existing 2x1 7FA.03 CCGT unit with TPM compared to a new 7FA.05 SCGT plant and to a new LM 6000 PH Sprint plant. TPM capacity not required for seasonal peaking in Case 2 was utilized to economically displace legacy coal energy.

Case 1: Existing 2x1 7FA.03 CCGT with TPM & New 1x1 7FA.05 CCGT

A sea level site was selected for the new 7FA.05 CCGT plant in New Orleans, Louisiana due to the proximity to natural gas supply from Henry Hub and due to lower regional plant construction costs. Gas Turbine World ISO CCGT capacity and heat rates were used and adjusted for degradation from "New and Clean" GT conditions and for an annual average ambient high temperature to reflect average on-peak dispatch conditions. Natural gas prices were assumed at $3.37/MMBtu based on the Energy Information Administration ("EIA") 2017 spot price and a transportation basis of $0.25/MMBtu was assumed.

To construct the new CCGT plant, EPC and Owner Costs were sourced from the 2013 EIA Utility Cost Report escalated to 2017 and adjusted for the New Orleans regional construction costs. Additional cost estimates for natural gas and electric transmission and substation construction were sourced from Black & Veatch's 2012 Cost and Performance Data for Power Generation Technologies report also escalated to 2017. Assumptions were made for site costs of $0.8 million (40 acres in Vermillion Parish, LA), transmission system upgrades of $5 million, one-mile transmission line construction of $2 million, substation interconnection modifications of $2.5 million, ten-mile natural gas lateral construction of $5 million and environmental permitting cost of $3 million. Overnight EPC construction was assumed at $941/kW with an 8.6% Interest During Construction rate. Plant O&M mobilization and staffing, spare parts (excluding GT capital spares) were estimated at $1.5 million and $1 million respectively based on industry experience. Commissioning fuel costs were conservatively assumed equal to test power energy sales revenue. These values generated a total project capital cost required to achieve plant commercial operation. No estimates were made for long term debt, owner equity costs, or return on capital investment as these are project specific.

Plant performance for the new CCGT plant is 359 MW at ISO and 334 MW at average daily high temperature with a dispatch heat rate of 6557 Btu/kWh LHV. Annual operating expenses after Commercial Operation included Variable O&M and GT Major Maintenance cost (including GT capital spare parts) of $3.91/MWh from the EIA Utility Cost Report. A fixed plant annual O&M of $4 million, annual property tax of $1 million and annual property insurance of $0.4 million were assumed from experience.

For TPM, an EPC capital cost of $400/kW, an environmental permit cost of $0.5 million, variable O&M of $2.5/MWh, output of 333 MW at a heat rate of 6728 Btu/kWh was assumed. A total of 49 TPM modules were required for 13 host 7FA.03 GT units. As TPM provides compressor airflow at ISO levels during all ambient conditions, the TPM capacity is not reduced due to higher than ISO ambient temperatures.

Case 2: Existing 2x1 7FA.03 CCGT with TPM & New SCGT Plant

The siting of the new SCGT plants was assumed to be at existing power generation facilities and considered as part of a long-term generation expansion plan. As a result, no capital costs are assumed for transmission system upgrades, electric transmission construction and natural gas interconnection or construction as it is assumed that these were initially sized and installed for full facility generation build out. Costs for substation interconnection consist of $0.6 million for the addition of a new substation bay. Environmental permitting for the SCGT units was assumed at $0.5 million. The new SCGT units are assumed to be in the same geographical location and as the previously presented new CCGT plant with the same assumptions for delivered natural gas pricing.

Since the new build SCGT units are used for seasonal peaking purposes, ambient temperature adjustments to output and heat rate were based on the average May through September high temperature. It was assumed that the SCGT units operating in peaking service would dispatch at a 14% annual capacity factor consisting of 150 starts per year and 8 hours of operation per start.

The TPM unit assumptions are the same as those used in Case 1.

III. Results

TPM provided a substantial capital cost advantage over the new build CCGT due to the significantly lower total project cost (EPC, interconnections and mobilization) of $436/kW versus $1160/kW for the new CCGT plant. TPM leverages physical plant, natural gas capacity, electric transmission capacity and substation interconnection that was designed, permitted and installed with the original 7FA.03 CCGT plant. An additional capital cost advantage for TPM is that the TPM capacity purchased at a $/kW value does not degrade with increasing ambient temperature while the new build CCGT capacity is purchased at ISO conditions but is only dispatchable on an annual average of 93% of the purchased ISO capacity. Capital cost for the two alternatives are shown in Table 1.

Table 1 Turbo Phase Versus New Build CCGT Capital Cost Summary (2017 k$)		
	Turbo Phase	1x1 7FA.05
Number of New Gas Turbines	0	1
Number of TP Modules	49	0
Number of Host 7FA.03 Turbines	13.0	0
Net Output at ISO - MW	333	359
Average Annual Net Output - MW	333	334
Power Plant EPC Capital Cost - k$	$133,780	$341,468
Substation & Transmission System Capital Cost - k$	$0	$8,000
Natural Gas Interconnection - k$	$0	$5,000
Interest During Construction - k$	$11,505	$30,484
O&M Mobilization & Spare Parts - k$	$0	$2,500
Total Project Capital Cost - k$	$145,285	$387,452
Turbo Phase Capital Savings - k$	$242,167	Base Case
Turbo Phase Capital Savings - %	62.5%	Base Case

The higher efficiency of the new build CCGT plant generates a lower annual fuel cost of $1.5 million compared to the TPM alternative. The annual fuel cost for the two alternatives is presented in Table 2.

Table 2 Turbo Phase Versus New Build CCGT Annual Fuel Cost Summary (2017 k$)		
	Turbo Phase	1x1 7FA.05
Annual GWH	2335	2340
Average Annual Net Heat Rate - Btu/kWh LHV	6728	6557
Production Fuel Cost - $/MWh	$26.91	$26.23
Fuel Cost - Annual - k$	$62,837	$61,383
Turbo Phase Annual Fuel Cost Savings - k$	-$1,454	Base Case
Turbo Phase Annual Fuel Cost Savings - %	-2.4%	Base Case

The annual fixed plant O&M, variable O&M & Major Maintenance and property taxes and insurance for TPM and the new build CCGT plant are shown in Table 3. TPM Major Maintenance is managed on a rotable exchange program basis. Rather than performing TPM major outages on site, as is the case with CCGT major maintenance, the TPM modules are exchanged and major maintenance performed in a shop setting.

Table 3 Turbo Phase Versus New Build CCGT Annual O&M Cost Summary (2017 k$)		
	Turbo Phase	1x1 7FA.05
Fixed Plant O&M - k$	$0	$4,000
Property Tax & Insurance - k$	$0	$1,400
Variable O&M & Major Maintenance - k$	$5,838	$9,150
Total Annual Plant O&M - k$	$5,838	$14,550
Turbo Phase Annual O&M Cost Savings - k$	$8,713	Base Case
Turbo Phase Annual O&M Cost Savings - %	59.9%	Base Case

TPM provided a significant capital cost advantage over the two SCGT alternatives at $437/kW compared to $966/kW for the 7FA.05 SCGT and $1071/kW for the LM 6000. Capital costs are presented in Table 3.

Table 3 Turbo Phase Versus New Build SCGT Capital Cost Summary (2017 k$)			
	Turbo Phase	7FA.05 SCGT	LM 6000 PH Sprint SCGT
Number of New Gas Turbines	0	1	4
Number of TP Modules	32	0	0
Number of Host 7FA.03 Turbines	8	0	0
Net Output at ISO - MW	195	231	224
Average Summer Peak Net Output - MW	195	198	198
Power Plant EPC Capital Cost - k$	$78,580	$175,624	$194,365
Substation & Transmission System Capital Cost - k$	$0	$643	$643
Natural Gas Interconnection - k$	$0	$0	$0
Interest During Construction - k$	$6,758	$15,159	$16,771
O&M Mobilization & Spare Parts - k$	$0	$100	$100
Total Project Capital Cost - k$	$85,338	$191,526	$211,879
Turbo Phase Capital Savings - k$	Base Case	$106,188	$126,541
Turbo Phase Capital Savings - %	Base Case	55.4%	59.7%

The TPM dispatch was analyzed in two ways. In order to accurately compare TPM to the SCGT alternatives, peaking service fuel costs and annual O&M costs were calculated for the approximately 235 GWh that the SCGT units are expected to dispatch annually. Since TPM provides capacity at the host 7FA.03 CCGT heat rate when operating in peaking service, an annual fuel cost savings is realized for TPM. Annual fuel costs are presented in Table 4.

Table 4 Turbo Phase Versus New Build SCGT Annual Peaking Service Fuel Cost Summary (2017 k$)			
	Turbo Phase	7FA.05 SCGT	LM 6000 PH Sprint SCGT
Annual GWH	234	238	237
Average Summer Peak Net Heat Rate - Btu/kWh LHV	6952	10,199	9480
Production Fuel Cost - $/MWh	$27.81	$40.80	$37.92
Annual Fuel Cost - k$	$6,513	$9,707	$9,005
Turbo Phase Annual Fuel Cost Savings - k$	Base Case	$3,193	$2,492
Turbo Phase Annual Fuel Cost Savings - %	Base Case	32.9%	27.7%

The annual O&M costs when operating in peaking service are presented in Table 5. Since the Major Maintenance cost of TPM is significantly less than that of the 7FA.05 SCGT, an annual O&M savings of $2.7 million is realized. The major maintenance cost of the LM 6000 and TPM are nearly equal.

Table 5 Turbo Phase Versus New Build CCGT Annual O&M Cost Summary (2017 k$)			
	Turbo Phase	7FA.05 SCGT	LM 6000 PH Sprint SCGT
Fixed Plant O&M - k$	$0	$0	$0
Property Tax & Insurance - k$	$0	$0	$0
Variable O&M & Major Maintenance - k$	$586	$2,680	$722
Total Annual Plant O&M - k$	$586	$2,680	$722
Turbo Phase Annual O&M Cost Savings - k$	Base Case	$2,094	$137
Turbo Phase Annual O&M Cost Savings - %	Base Case	78.1%	18.9%

TPM is capable of generating 1,368 incremental GWH assuming the host 7FA.03 CCGT is dispatched at an 80% capacity factor. After dispatching TPM for 234 GWH in peaking service, there remain 1,134 GWH of dispatchable energy at an average heat rate of 6952 Btu/kWh LHV. As the value of this additional capacity varies significantly based on the particular energy markets, utility rate structures and power sales agreements, this incremental energy value can only be reasonably estimated on a project specific basis. For purposes of this analysis, it is assumed that a utility fleet includes both 7FA.03 CCGT plants and 1980s vintage coal plants. The additional TPM capacity of 195 MW and energy of 1,134 GHW are assumed to economically displace coal unit capacity and energy. The coal plant heat rate is assumed at 10,000 Btu/kWh and delivered fuel cost at $3.12/MMBtu. Coal plant variable O&M was assumed at $4.5/MWh base on the EIA report.

The TPM displacement of coal energy generates annual fuel cost savings of $4 million and annual plant level variable O&M savings of $2 million excluding costs relating to environmental emissions credits.

Table 6

Turbo Phase Displaces Coal Energy
Annual O&M and Fuel Cost Summary
(2017 k$)

	Turbo Phase	Coal Unit
Annual Generation - GWH	1134	1134
Average Summer Peak Net Heat Rate - Btu/kWh LHV	6952	10,000
Production Fuel Cost - $/MWh	$27.81	$31.22
Annual Fuel Cost - k$	$31,525	$35,391
Turbo Phase Annual Fuel Cost Savings - k$	Base Case	$3,866
Turbo Phase Annual Fuel Cost Savings - %	Base Case	10.9%
Incremental Fixed Plant O&M - k$	$0	$0
Incremental Property Tax & Insurance - k$	$0	$0
Variable O&M & Major Maintenance - k$	$2,834	$5,102
Total Annual Plant O&M - k$	$2,834	$5,102
Turbo Phase Annual O&M Cost Savings - k$	Base Case	$2,267
Turbo Phase Annual O&M Cost Savings - %	Base Case	44.4%

IV. Risk Assessment

The risks inherent in new power plant construction and operation and the risks relating to the TPM alternative are:

Siting Risk:

The selection of a site for a new power plant must balance proximity to natural gas lines, electric transmission interconnection, water availability, local environmental constraints and land availability. If the site is near a load center, public relations issues must be addressed including impacts that the plant may have on neighbors and the general public. Locating new plants away from load centers increases the cost of transmission system upgrades required to deliver the power from the new plant to the load centers. TPM eliminates these risks since the TPM equipment is located at existing power plants and utilizes existing natural gas, electric transmission, transmission system interconnection and water infrastructure.

Construction Risk:

For the addition of SCGT units at an existing power plant, there is risk associated with construction activity on the new units taking place in close proximity to operating units. TPM mitigates much of this risk, as the system is modular with minimal local construction activity required and no construction activity required in the plant switchyard or substation. Operating units require only a short outage to make the final TPM interconnections at the compressor discharge.

Investment Risk:

For both cases, the addition of a new CCGT plant or new SCGT units require that the capacity be installed in advance of the system demand for the new capacity. This results in near term “stranded capital” until the demand increases to match the capacity installed. Consider a mid sized utility with a 5,000 MW peak demand and annual load growth of 1% or 50 MW per year. The new CCGT plant will normally be commissioned in time to meet the first year 50 MW demand increase but will not be fully needed for over 6 years as the system demand “grows into” the full capacity. The early investment of capital required to install capacity in “block” sizes results in a higher near term capital cash flow and potentially a non-optimum near term return on capital.

TPM can be added in increments of 6.8 MW per module. This allows for increasing generating capacity in increments that match annual demand increases. This generates improved capital cash flow and a more optimal capital return.

Long Term Cost Risk:

The new CCGT plant will require additional staffing for operation and maintenance while the TPM installation requires no additional staffing at the existing host CCGT plant. Additional long-term costs incurred at the new CCGT plant include property taxes, property insurance, balance of plant O&M and increased inventory with associated working capital carrying costs. These costs are avoided with the TPM alternative.

Operating Risk:

The addition of 334 MW of a new 1x1 CCGT plant or 198 MW of a new SCGT unit includes normal operating risk. Forced outages on these GT units result in a system loss of the complete capacity of the unit. Planned outages, while typically taken during non-peak times with a lower system economic impact, also result in loss of full unit capacity for the duration of the outage.

TPM consists of a series of distributed modules with 4 modules associated with each host 7FA.03 GT. When the host GT experiences a forced or planned outage, the TPM capacity lost is only 24 MW as compared to 198 for the SCGT and 334 for the CCGT gas or steam turbine units. TPM provides less transmission system operating risk and lower replacement power costs for forced outages.

In addition to serving as intermediate or base load capacity and energy, TPM is capable of fast start and load following operation. To the extent that a system operator is utilizing 7FA.03 CCGT units for Automatic Generation Control ("AGC") or load following, a heat rate penalty is incurred when dispatching the CCGT unit at less than full load. The use of TPM for AGC does not result in a heat rate penalty and allows for lower total system fuel cost as compared to using CCGT for AGC.

V. Conclusion

TPM provides substantial economic and operational benefits when compared to new build CCGT and SCGT alternatives for meeting increases in electricity demand. Optimized capital cash flow and the elimination of long term fixed costs associated with new plants are also realized.

Capital cost of the TPM option is substantially lower than the CCGT and SCGT options as TPM up-rates existing generating assets by restoring latent GT capacity otherwise lost due to ambient temperature or operating limitations. Leveraging existing power plant and transmission system infrastructure further reduces project capital cost, annual fuel cost and annual O&M cost when compared to alternative technologies.

For more information or review of this analysis as well as discussion regarding the applicability of this analysis to specific fleets or markets, please contact:

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Appendix I

Key Model Assumptions

- Capacity degradation from “New and Clean”: CCGT at 2.5%, SCGT at 2.5%, TPM at 0%
- Heat Rate degradation from “New and Clean”: CCGT at 2%, SCGT at 2%, TPM at 2% (reflecting host 7FA.03 CCGT degradation)
- New plant EPC cost: CCGT at $941/kW, 7FA.05 SCGT at $758/kW, LM 6000 SCGT at $864/kW, TPM at $400/kW
- New CCGT plant interconnection, “off site” costs and annual O&M costs:
    - Transmission system upgrades at $5 million
    - 1 mile transmission line construction (plant to interconnection point) at $2 million
    - Substation interconnection at $1 million
    - 10 mile natural gas line & interconnection at $5 million
    - Environmental permitting at $3 million
    - 40 acre site acquisition at $0.8 million
    - Interest During Construction rate at 8.6% (excluding owner overheads)
    - Plant O&M mobilization, staffing, training, procedure development and commissioning labor at $1.5 million
    - Plant spare parts (excluding GT capital spares) at $1 million
    - Fixed annual plant O&M at $4 million
    - Annual property tax and property insurance at $1.4 million
- New SCGT unit interconnection, “off site” costs and annual O&M costs:
    - Substation interconnection at $0.6 million
    - Environmental permitting at $0.5 million (also used for TPM)
    - Plant spare parts (excluding GT capital spares) at $0.1 million
- Operating costs:
    - Delivered natural gas for all units at $4/MMBtu
    - New CCGT Plant:
        - Capacity factor at 80%
        - 7FA.05 major maintenance at $3.91/MWh
    - New SCGT Plant:
        - Capacity factor at 14%, 150 annual starts, 8 operating hours per start
        - LM 6000 PH Sprint demineralized water at $0.05/MWh
        - LM 6000 PH Sprint variable O&M (major maintenance) at $2.99/MWh
        - 7FA.05 variable O&M (major maintenance) at $11.26/MWh

- TPM
  - TPM variable O&M and major maintenance at $2.5/MWh
- 1980s Vintage Coal Plant:
  - Net heat rate at 10,000 Btu/kWh
  - Delivered coal cost at $3.12/MMBtu

Appendix II
Data Sources

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